2.7 Frogs and wetlands

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Abstract

Australian frogs are remarkably diverse in their life styles and their use of wetlands. Our understanding of the ecological needs of frogs is incomplete but we do know some of the major requirements for survival, such as the need for clean water, the need for safe foraging areas, the need for shelter from predators and adverse weather conditions, the need for minimal habitat stress (as this increases the susceptibility of frogs to disease). The design of wetlands must take into account these over-riding requirements, plus the specific requirements that are unique to each frog species. In this paper, I refer to the management of the Green and Golden Bell Frog during the establishment of the Sydney Olympic site as an example of sorts of considerations that are required in managing frogs and wetlands.

Australian Frogs

There are about 250 described frog species in Australia (Anstis 2013). This is a surprisingly high number of frog species for such an arid continent. Australian frogs have had to adapt of the vagaries of Australia's climate and can survive in areas where you would not expect them to be. Frogs can be found in from coast to coast, in the great desert that span central Australia, to the alpine areas of the Snowy Mountain Ranges, from the rainforests of north Queensland to the very southern tip of Tasmania. The adaptability of frogs is their strength and it allows them to inhabit a range of wetland (and not so wet) sites.

All frogs need water to survive and to breed. In Australia, frogs cannot rely on predictable seasonal rainfall (except for the monsoonal north) and so they have developed several strategies to help them survive; such as:

- Elongated life span;
- Increased mobility;
- Cryptic colouration and body patterns;
- Cryptic behaviour;
- Water storing ability; and
- Laying eggs on land (or carrying them).

Despite this armoury of survival skills, frogs are still in decline.

Global Decline of Frogs

Ever since humans started clearing land, damming rivers and changing the pattern of freshwater flow in ecosystems and polluting the landscape, frogs have been in decline. However, in the 1980s it became apparent that some other factor was in operation that was responsible for the decline and extinction of frogs in remote areas ranging from the cloud forests of Costa Rica to the prairies of central America and parts of Australia. Frogs were dying and there was no apparent cause.

Over the last twenty years, a lot of research has gone into frog declines and it appears that several factors are at play (MacCallum 2007); the main factors being:

1. Water pollution: tadpoles are extremely sensitive to water-soluble chemicals and can be killed when exposed to incredibly low levels of certain pollutants. The worst pollutants are detergents, pesticides (such as insect sprays), herbicides and oil-based chemicals;
2. Air pollution: massive amounts of Sulphur Dioxide and Nitrogen Dioxide (and other gases) have been released into the atmosphere since the Industrial Revolution. These gases combine with moisture in the air and create toxic substances that kill frogs, other animals and plants. In the northern hemisphere, this is often described as "acid rain";
3. Elevated UV levels caused by the reduction of the ozone layers. Eggs laid by frogs on land or in shallow water will be sterilised by the high levels of incident UV; and
4. Disease: several new exotic diseases are prevalent in Australian frogs. Many of these diseases are exacerbated by environmental stress. In Australia, the main diseases of concern are Frog Chytrid Disease, Ranavirus and Redlynchia.

The combined impacts of these various factors has resulted in many frog extinctions and the reduction of many frog populations world-wide (Stuart *et al*. 2004).

Frog Habitat Requirements

All frogs have essential habitat requirements, without which they cannot survive. These essential requirements include availability to clean water, food, shelter from extreme weather events and predators, safe movement corridors, low environmental stress and protection from disease (e.g. Wassens *et al*. 2008).

Access to Water and Water Quality

All amphibians have highly permeable skin. Thin, permeable skin allows amphibians to absorb moisture directly from the air or moist surfaces without drinking. It also allows gases to pass across the body lining, facilitating respiration. But having a permeable skin also means that contaminants in water are readily absorbed and accepted into body tissues. Clean water is critical for survival.

In many urban and peri-urban areas, creek water is often adversely affected by contaminated run-off; either as agricultural run-off (which may contain pesticides, herbicides, high levels of organic wastes) or urban run-off (which may contain detergents, pesticides, sewage or oil-based chemicals). In addition to these contaminants, urban run-off often contains high levels of salt and silt. The combined effects of high nutrient run-off result in excessive bacterial growth in water bodies and/or cyanophyte (blue-green algae) proliferation. These situations are lethal to frogs (see Tyler 1989 for a review of the impacts of pollutants on frogs).

Food Resources

Tadpole and frog's food requirements are very different. Most tadpoles are herbivorous and feed by either swallowing free-floating algae or by rasping substrate-bound algae using their mouthparts. Some tadpoles may filter-feed and hence consume surface algae and bacteria in pond water.

Frogs are predators. Most frogs feed primarily on terrestrial or flying insects, although other invertebrates are also taken. Larger frogs may consume small vertebrates, such as small rodents, lizards, fledgling birds and bats. Frogs mainly hunt at night and rely on their ability to detect slight movements at night. Foraging frogs are at risk of predation themselves and usually frogs will hunt in areas where there is sufficient ground cover to allow them to retreat in the event of a would-be predator.

Many of the insects that frogs feed upon occur in terrestrial ecosystems, such as grasslands, wetland margins or in woodland. Land clearing has resulted in the loss of many foraging areas. In addition, the widespread use of pesticides and other agricultural chemicals means that many of the prey items consumed by frogs contain a cocktail of sub-lethal chemicals that may result in incapacitation or death to the frog.

In urban areas, ground cover is often sparse and high levels of night lighting increases the risk of predation of frogs.

Availability of Breeding Habitat

Breeding sites are species-specific: some frogs breed in still water, others in flowing water; some breed in warm water, others in cooler water; some breed in shaded sites, others need full sun; some breed in ephemeral sites, others in permanent water sites, and some Australian frogs do not breed in open water but will breed in damp soil sites.

The type of breeding sites required is related to the food requirements of the larvae, the need to avoid predation of the eggs and larvae and the nature of the surrounding environment. Frogs will try to maximise the chances of survival of their young by spawning in sites where there is a high chance of developmental success. If secure breeding sites do not exist, the species will dwindle in number as the adult population ages and no new young adults emerge to replace them

Figure 2.7.1. *Litoria chloris*, the Red-eyed Tree frog, a species that often breeds in ephemeral puddles.

Most frogs try to avoid breeding in sites where fish are present and where the water is contaminated (Figure 2.7.1).

Refuge Areas

All animals have to withstand extreme environmental conditions from time to time in order to survive. For frogs, the hardest times are during extreme dry periods or during extreme cold periods. In addition, frog needs refuge sites to be able to escape predators.

During times of favourable weather conditions, frogs will forage for food, seek a mate or disperse. Each of these activities has an associated risk, particularly from predators. Frogs try to reduce predation risk by being most active at night when predators are less abundant, by exploiting cryptic body colours and patterns and body postures, and by avoiding areas where they cannot retreat quickly to escape predatory attacks. Diurnal and nocturnal refuge areas are usually associated with areas of thick ground cover vegetation where frogs can quickly retreat into and escape. Frogs will also utilise other ground cover items such as logs and rocks and fallen branches, but may similarly utilise artificial shelter sites such as sheets of timber, metal, discarded household items such as old electrical appliances, dumped cars and building waste.

During periods of extreme weather conditions (i.e. extremely cold or extremely dry) frogs seek more substantial shelter environments (referred to as "over-winter habitat"). Over-winter habitat comprises a cool, thermally stable site where ground moisture or humidity is similarly low but stable. The site must also be free from physical disturbance. Frogs may utilise over-winter sites for just a few days at a time or may remain in a semi-dormant state there for several months until outside conditions improve.

The lack of over-winter sites has proven to be critical for the survival of managed populations of frogs and experiments are currently underway to investigate that most effective ways to create effective over-winter habitat in urban and managed areas. In the past rocks piles and logs piles have been trialled as over-winter habitat with only moderate success. While these types of over-winter sites will be used by frogs, they are also used by frog predators.

Dispersal requirements

Australian frogs move around a lot, some species (e.g. the Green and Golden Bell Frog) are capable of dispersing several kilometres during a season. For many frogs, dispersal movements are more modest and may only be a few hundred metres per season. During dispersal, frogs are often forced to move away from safe shelter areas and to traverse unfamiliar and perhaps more open ground. Deaths to predation, dehydration and lack of food can be high.

Frog dispersal may be seasonal and may not be enacted by all members of the population. From the viewpoint of the species, the most significant dispersal period occurs immediately after metamorphosis. Many young frogs set out to try to locate new wetland sites that they can exploit. Many will not survive but some will succeed and ensure that the species continues on (Penman 1998). Because frogs produce large numbers of juveniles, early stage dispersal is critical to prevent over-crowding around the breeding pond and to enable the establishment of new sub-populations (an essential pre-requisite for the development of greater genetic variation in the species). In over-crowded sites, cannibalism rates are high and often juvenile frogs are consumed by their own species or by other frog species.

Small-scale frog movements usually occur after rainfall or when insects are active. Frogs move around in search of food but also to try to find new freshwater sites to colonise. Frogs normally avoid areas lacking refuge sites because of the risk of predation thus they tend to move in areas where there is ample ground cover such as along a vegetated water course, damp cliff line or mossy rock ledge.

Frog Wetland Habitats

For frogs to survive in a wetland, the wetland must provide all (not just some) of the frog's habitat requirements. Artificial wetlands have been created with frogs in mind and have failed because they have neglected one or more of the frogs' habitat requirements. It is too simplistic to imagine that by merely creating a pond environment with reeds and water that frogs will flourish. Often these areas will be initially colonised by frogs but after a season or two the site remains as a quiet testimony to our faulty understanding of the needs of these animals (White 2001).

Amongst the Australian frogs are a variety of different breeding, foraging and movement strategies that have been adapted to exploit one or more wetland type. The type of wetland available will restrict the frog species that are capable of exploiting it. Wetlands vary greatly in their size, permanence, salinity, dissolved oxygen content, inorganic and organic solute content and temperatures. Table 2.7.1 below presents a simplified list and selected characteristics of a range of wetland types.

Frogs that utilise the wetland types

There are many physiological and behavioural factors that limit which species of frog are able to exploit particular wetlands. One of the most significant factors is the physiology of the tadpole (see Anstis 2013 for overview). Some tadpole have mouthparts that are designed for filtering suspended organic material or single-celled organisms from the water; these tadpoles thrive in shallow, highly ephemeral pools and puddles. They are often poor swimmers but have accelerated development. Some tadpoles have enlarged, keratinised denticles inside the buccal disc, these denticles are used to scrape surface algae from

Table 2.7.1. Characteristics of wetland type where frogs may be found.

	Duration	Salinity	Temp Variations	Dissolved Oxygen Levels	Other Animals Present	Vegetation Present	Other
Puddles	Very short (few hours to a few days)	Nil or trace	Extreme Very hot in day	Very low Zero in day	Nil	Nil	Small but locally common
Pools	Medium (few weeks to a few months)	Nil or trace	Moderate temp fluctuations	Low, may be zero at times	Aquatic insects	Some rushes or reeds, Algae	Small but widely scattered
Primary creeks	Very short (few hours to a few days)	Nil or trace	Moderate temp fluctuations	High	Nil	Algae	Abundant in steeper areas
Secondary creeks	Medium (a few weeks to several months)	Low	Minor temperature changes	Medium to high	Aquatic insects, crayfish, snails	Algae, Mosses, Reeds	Present in most gullies and minor valleys
Rivers (Figure 2.7.2)	Permanent	Low to high	Minimal or no temperature changes	Medium to low	Aquatic insects, crayfish, shrimp, snails, fish	Reeds, Rushes,	Present in major valleys
Ponds (Figure 2.7.3)	Permanent or semi-permanent	Low to high	Minor temperature changes	Medium to low	Aquatic insects, crayfish, shrimp, snails, fish	Algae, Rushes, Reeds, Floating vegetation	Isolated
Lakes (Figure 2.7.4)	Permanent	Low to high	Minimal or no temperature changes May be stratified	Medium to low May be stratified	Aquatic insects, crayfish, shrimp, snails, fish	Algae, Rushes, Reeds, Floating vegetation	Present in major depressions

submerged rocks. These tadpoles occur in flowing water, are good swimmers and have an extended tadpole life.

To better explain these points, listed in Table 2.7.2 below are some common frog species that occur in south-eastern Australia that utilise pond sites.

Frog Disease Control and The Frog Hygiene Protocol

One of the major factors in frog declines in Australia has been the introduction of exotic frog diseases. Of these, the most studied but most infectious is Frog Chytrid Disease (or chytridiomycosis). This disease is caused by a small, single-celled fungus that destroys the basal skin keratin layers of frog, causing massive electrolyte loss, kidney malfunction and hormonal stress (Berger *et al.* 1999). The pathogen (small fungal spores) are easily

Figure 2.7.2. Riverine wetland, Murrumbidgee River near Canberra.

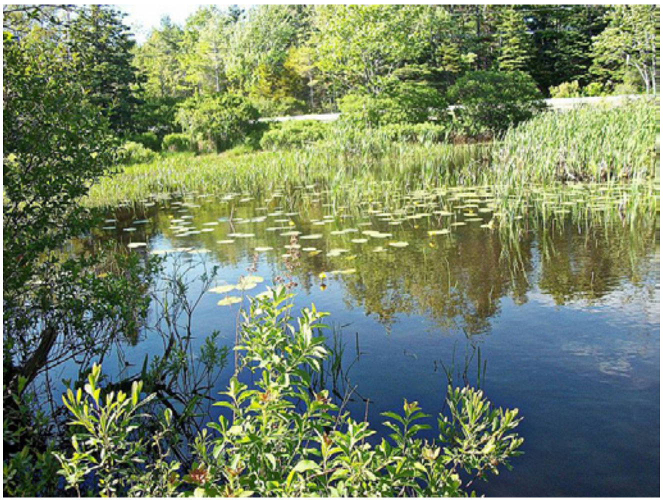

Figure 2.7.3. Pond habitats may be large and fairly permanent.

Figure 2.7.4. Longneck Lagoon, near Windsor. A large wetland site.

transferred in most damp materials such as mud on boots, moist plastic bags or by direct handling of infected animals.

Chytrid infection has been devastating to frog species causing extinctions worldwide. The disease has now been recorded in four regions in Australia - the east coast, southwest Western Australia, Adelaide, and more recently Tasmania. In mainland Australia chytrid has caused the extinction of one frog species (*Taudactylus diurnis*), and has been associated with the extinction of three other species (*Rheobatrachus silus*, *R. vittelinus* and *T. acutirostris*). In addition, the population size and status of many other frog species has declined or isolated populations have been lost.

Amphibian population declines due to chytrid disease can occur very rapidly; there are documented cases of deaths occurring within only a few weeks after infection (Lips *et al*. 2006). Species that occur over a very small geographic area, have highly specialised environmental requirements or have low population numbers to begin with are at particular risk of extinction to this disease (Smith *et al*. 2009).

Highly infectious and virulent disease like chytrid have prevented some frog habitat creation from succeeding (e.g. Green and Golden Bell Frog at Woonona; White 2001). The creation of wetland habitats for frogs must take into account the likelihood of disease and instigate measures to monitor and respond to outbreaks of the disease.

The Frog Hygiene Protocol (DECC 2008a) was developed to provide guidelines about how to limit the spread of frog pathogens and provided a series of recommended procedures for protecting sites from infection.

Table 2.7.2. Pond Frog Species.

Wetland Type	Frog Species	Common Name	Frog Adaptations
Ponds in Wallum Habitat	*Crinia tinnula* *Litoria freycineti*	Wallum Froglet Wallum Rocket Frog	Tadpoles able to withstand low water pH and high tannin levels.
Ponds in Coastal Open Woodland	*Litoria verreauxi* *Litopria jervisiensis* *Litoria peronii* *Litoria latopalmata* *Litoria tyleri* *Litoria ewingi* *Litoria fallax* *Litoria caerulea* *Paracrinai haswelli* *Crinia signifera* *Limnodynstes tasmaniensis*	Verreauxs Frog Jervis Bay Tree rog Perons Tree Frog Broad-palmed Frog Tylers Tree Frog Ewings Tree Frog Eastern Dwarf Tree Frog Green Tree Frog Haswells Frog Common Eastern Froglet Spotted Grass Frog	Tadpoles able to withstand water temperature fluctuations and consume a generalised diet.
Ponds in Coastal Wet sclerophyll forest	*Litoria revelata* *Litoria tyleri* *Litoria chloris* *Mixophyes fasciolatus*	Whirring Tree Frog Tylers Tree Frog Red-eyed Tree Frog Great Barred Frog	Tadpoles able to withstand low light conditions, high organic acid levels in water
Ponds associated with coastal lagoon (saline)	*Litoria aurea* *Litoria fallax* *Limnodynastes peronii* *Crinia signifera*	Green and Golden Bell frog Eastern Dwarf Tree Frog Striped Marsh frog Common Eastern Froglet	Tadpoles able to tolerate low salt levels
Ponds in mid-altitude areas	*Litoria verreauxi* *Litoria lesueuri* *Pseudophryne bibroni* *Pseudophryne dendyi*	Verreauxs Frog Stony Creek Frog Bibrons Toadlet Dendys Toadlet	Tadpoles able to tolerate prolonged cold periods without feeding.
Ponds in high altitude areas	*Litoria verreauxi alpina* *Litoria daviesae* *Pseudophryne corroboree* *Pseudophryne pengilleyi*	Alpine Tree Frog Davies Tree Frog Southern Corroboree Frog Northern Corroboree Frog	Tadpoles able to tolerate temperatures below freezing and long periods without feeding

Case Study: Developing Habitat for the Green and Golden Bell frog at Sydney Olympic Park

The Green and Golden Bell Frog (Figure 1) gained considerable notoriety in Australia because of its presence in the Sydney Olympic Site. The 2000 Sydney Olympic Games were a highly successful international event and one that brought tremendous credit to this country and the organisers. But one of the greatest achievements of the 2000 Olympic Games was the fact that the largest public construction undertaking in this country took place without destroying the habitat of a threatened frog species: the Green and Golden Bell Frog.

Initial Discovery

The Green and Golden Bell Frog was first reported in the Homebush Bay brickpit in 1991 (A. White pers. data). The species had been known from other nearby sites, such as Mason Park at Homebush. Its presence in the brickpit was a surprise and an inconvenience. At the time, a Private Members Bill was being passed in the New South Wales' parliament that was to allocate special protection for threatened species in this state. The first species to be appended to that Bill was the Green and Golden Bell frog. Green and Golden Bell Frogs were well known to many Sydneysiders as the species had been widespread and locally abundant. Being a spectacularly marked frog and one that basks during the day, it was a species that was regularly sighted, at least up until the 1970s. During the 1970s and 1980s the species underwent a massive decline with widespread local extinctions (White and Pyke 1996).

Homebush Bay Industrial Area

The Homebush Bay area was an old industrial area that was due to rebuilding. The site contained several noxious industries including a coal gas storage facility, abattoirs and leather tanning factories, paint factories and assorted smaller manufacturing plants. The site was severely contaminated with heavy metals, industrial effluent and other industrial wastes. The State Government of the day developed a re-development strategy for the site that would entail a massive rehabilitation of the contaminated areas before a new industrial area could be rebuilt.

However, in 1992, it was decided that Sydney would make a bid for the 2000 Olympic Games and that if successful, Homebush Bay would the location for the games. One of the major announcements associated with the Games bid was that the Sydney Games would be the "Green Games". The Sydney Olympic site would undertake world's best practices in environmental rehabilitation and restoration to revamp the old, contaminated industrial wasteland into an attractive but clean Games venue. The conservation of the Green and Golden Bell Frog at Homebush Bay became part of the Olympic bid.

In 1993, Sydney was confirmed as the approved venue for the 2000 Olympics and so the government quickly set about forming management committees, setting up operational structures and start planning how best to remediate and re-develop the site.

Bell Frog Studies Begin

In late 1992 I was sub-contracted by the state government department Property Services Group to begin to collect data on the distribution

Figure 1. Green and Golden Bell Frog *Litoria aurea*.

of the Green and Golden Bell Frog at Homebush and to eventually come up with a plan for the conservation of the species on the site. At the time, extensive demolition works were underway and the abattoirs, tanneries and associated factories were being pulled down. A plan for the reshaping of the site had been developed with landscaped hills to be created to deal with the mountains of brick and concrete rubble that would be created during the demolition works. The most notable of these landscaped features was Kronos Hill.

By mid-1993, I had determined that the Green and Golden Bell Frogs were not just confined to the Old State Brickpit at Homebush Bay (Figure 2) but were present in several other areas including the RANAD Site (Royal Australian Naval Armament Depot at Newington). Bell Frogs were also present on the old State Abattoir site as well as in other dis-used industrial areas.

In 1993, the Olympic Coordination Authority (OCA) was formed. The primarily responsibility of this group was the construction and oversight of the Olympic site. As Bell Frogs were present in demolition areas as well as areas for new construction, measures were required to protect the frogs during this period of intense construction. All Bell Frog studies were transferred to the OCA, as a result I had to attend planning meetings and propose measures

Figure 2. Panorama of the Old State Brickpit, Homebush Bay.

to protect the frogs during the works. At this stage of development, the only area where Bell Frogs had secure breeding sites was in the Old State Brickpit and so the Brickpit became "core habitat" for the species and its protection was regarded as critical for the survival of the species at Homebush.

Two of the major initiatives in protecting Bell Frogs during the construction frenzy was to erect frog-exclusion fences to prevent the frogs from entering dangerous work areas. In addition, Bell Frogs in dangerous sites were collected by hand and relocated into safer sites. In some areas that were devoid of ground cover vegetation, shelter boards were laid down for dispersing frogs to use.

But a definite, scientifically-based plan was needed for the long-term conservation of the species. To do this statistically-reliable data was needed and so a monitoring program was initiated using a marked-recapture system to identify individual frogs. Data collected during 1993, 1994 and 1995 was used in the preparation of a Fauna Impact Statement (FIS) to assess the potential impacts of the works on the frogs inside the Brickpit (Greer 1994). The following year, a second FIS was carried out to cover the sites outside of the Brickpit where the frogs were present (Pyke 1995).

Darkovich and O'Meara (2008) give a detailed account of the legislative and planning requirements that applied to the conservation of the Green and Golden Bell Frog at the Sydney Olympic Site.

Habitat Creation for Bell frogs

In 1994, the first Bell Frog ponds were constructed. This was the first attempt to create habitat de novo for any animal species in Australia. At the time, our knowledge of the habitat requirements of Bell Frogs was sub-standard and the first ponds constructed (Hockey Ponds) were dismal failures. Bell Frogs never colonised these ponds and while this was a big disappointment it highlighted the lack of knowledge and the need to collect rigorous ecological data about this species before attempting to manage it. Of course, the Olympics were not going to wait for the scientific studies to be completed and so many ponds were constructed on a trial and error basis.

The second set of ponds to be created were trial ponds and were designed specifically for Bell Frogs. The Hockey Ponds had not worked because their design was compromised by landscaping considerations. What was needed were test ponds that could be established away from public view. The Golf Ponds were two small ponds constructed along the edges of the newly-constructed golf driving range. These ponds had an inclined base (i.e. they had a deep and a shallow end). They also had a controlled water supply and could also be emptied on demand. This facility meant that the amount of water in the pond could be varied according to our intention. It had been noted many times that Bell frogs often bred in very simple waterbodies that were often not much more than a scrape in the ground with some water in it. Elaborate ponds that contained a variety of water plants

Figure 3. Rock piles, and smaller ponds constructed inside the Old Brickpit, Homebush Bay.

and had set water levels were continuously ignored by the Bell Frogs. It seemed that newly created wet areas had some special attraction for Bell Frogs and if these waterbodies remained as permanent ponds that developed a more complex vegetation assemblage and animal assemblage, they became less useful as habitat to Bell Frogs (White 1995).

In the Golf Ponds we had the first opportunity to test this theory. The ponds were constructed in 1994 and remained in place until 1997. In the first year of their existence the ponds had limited fringing vegetation but had a well-established ring of emergent vegetation (*Typha orientalis*). Twice a year this vegetation was cut back to prevent it overgrowing the ponds: areas of open water were maintained. In addition, once a year one pond was allowed to become almost dry, and in the next spring was refilled to flooding level. Bell Frogs quickly colonised these ponds and bred in them.

As a further test of the role of fluctuating water levels and disturbance, in the final year the vegetation was not cut back and water levels remained static. Within 12 months, Bell Frogs abandoned the ponds and never returned (Pyke and White 1999).

The design of the Golf Ponds was the yardstick for the design of many future ponds. In the Master Plan (Homebush Bay Corporation 1994) for the site, many waterbodies were proposed, some were primarily for stormwater control, others primarily for landscaping purposes and others solely for frog conservation. The frog ponds were of two primary types: small, regularly spaced “stepping stone” ponds that were established to assist dispersing frogs, and larger, but less frequent breeding and shelter ponds. Each of these ponds had a wall of sandstone incorporated into them to provide potential “over-winter” habitat and had tussock plant established around the rock wall as additional shelter and to encourage insect prey (see Pyke and White 1996, Pyke *et al*. 2002 for habitat determinants).

The long-term conservation of Bell Frogs at Homebush Bay depended on not confining the species to a few isolated ponds. Instead, a concept of a series of ponds dotted across the Olympic site was developed (AMBS 1996, 1997; Figures 3 and 4). This concept required the construction of frog underpasses beneath internal roads, the allocation of land in strategic locations for frog ponds and the establishment of vegetation cover that would serve as foraging areas or shelter areas for the frogs. In all of these deliberations, there were conflicts with road planners, infrastructure planners, landscapers and engineers who had other priorities in creating the Olympic site.

Fickle Bell Frogs

One of the most frustrating aspects of creating habitat for any species occurs when that species shuns your newly created masterpiece. At Homebush, there was enough space to be able to trial various pond designs. As a result of these trials, we now have a much better understanding of the specific requirements of

Figure 4. Large wetlands, Narawang wetlands, Homebush Bay.

Green and Golden Bell Frogs. But the frogs still have other behavioural aspects that can thwart our best intentions.

In 1996, three identical ponds were constructed near the Archery area (called ponds A1, A2, and A3). The ponds were quite large, being more than 50 metres long and had simple plantings established within the pond and in the near surrounding areas. Pond A1 was immediately colonised by Bell Frogs but ponds A2 and A3 were ignored (despite being identical in all ways). Bell frogs were physically relocated from ponds A1 to A2 and A3 to see if they would remain there, but they didn't. They quickly returned to A1 where there was a steady chorus of calling male Bell Frogs.

To this day, we do not believe that there were any differences in the ponds that would explain this behaviour in the frogs. Recent research has indicated that Bell Frogs (especially males) respond to other calling males of their own species by congregating around them. The purpose of this behaviour is not clear but it may serve as a means to increase the attractiveness of the area to female frogs.

Non-breeding Sites

Another critical piece of research that was carried out at Homebush concerned sexual spatial patterns. It became clear early on that when male frogs congregated around ponds and began calling, this had two impacts: firstly, there was intense competition for space and food in a small area, and secondly, it was a dangerous place for any small animals (such as metamorphosing frogs). Other nearby ponds that were not occupied by calling male frogs may have been colonised by non-breeding female frogs. It appears that non-breeding female frogs avoid male frogs up until the time of spawning. This behaviour may prevent forced releases of immature eggs (White and Pyke 2002).

Immature Bell Frogs face a difficult and dangerous time during metamorphosis. The site where they are about to emerge may be ringed with a high number of hungry male frogs that are not prepared to give up their calling sites. Cannibalism of the young frogs will be high under these circumstances. Young frogs need to be able to escape from their spawning pond and disperse safely to less densely occupied pond site.

The Result

When the Olympic Games commenced in 2000, there was a healthy colony of Green and Golden Bell Frogs present in the brickpit site but also spread across the rest of the Olympic area. Despite the numerous trial and error mistakes that were made with establishing habitat for the Green and Golden Bell Frogs at Homebush this project still stands as a wonderful example of successful conservation in the wake of the largest civil engineering project in Australia.

Conservation efforts for the Bell Frogs did not cease after the Olympics Games had finished. The later created Sydney Olympic Park Authority has also undertaken a program of monitoring the Green and Golden Bell Frogs and extending habitat. New habitat areas have been created in Blaxland Common and along the Parramatta River (Muir 2008). Additional measures such as the control of the Plague Minnow Gambusia holbrooki were initiated (O'Meara and Darkovich 2008). Habitat management remains a high priority and the frogs are still a flagship species for Homebush Bay.

Another offshoot of the habitat research that took place at Homebush Bay was the production of a guide for developers or conservationists who wanted to recreate habitat for the Green and Golden Bell Frog (DECC 2008b).

Conclusions

The management of wetland areas for frogs is not a simple undertaking. The reliance of frogs on access to clean water means that the catchments of wetlands must be kept as free of contamination as possible. In addition, frogs have a number of habitat requirements that must also be met. Despite these difficulties, wetlands have been successfully managed for frogs and as our knowledge of the specific habitat requirements of each frog species improves, the opportunities to manage additional and more problematic wetlands will become possible.

References

AMBS Consulting (1996). Management Plan for the Green and Golden Bell frog. Prepared for Olympic Co-ordination Authority, Sydney.

AMBS Consulting (1997). Strategy for the Conservation of Green and Golden Bell Frog at Homebush Bay. Internal working document prepared by Australian Museum Business Services for Showground Precinct) located within the area of the 1995 Homebush Bay Olympic Precinct. Prepared for Olympic Co-ordination Authority, Sydney.

Anstis, M. (2013). 'Frogs and tadpoles of Australia.' (New Holland Publishers: Sydney.)

Berger, L., Speare, R., and Hyatt, A. (1999). Chytrid fungi and amphibian declines: overview, implications and future directions. In 'Declines and Disappearances of Australian Frogs'. (Ed A. Campbell.) pp. 23–33. (Environment Australia.)

Cogger, H. (1995a). Fauna Impact Statement for Proposed Golden Bell Frog at Homebush Bay: Roads Infrastructure. Prepared Development Works within the 1995 Homebush Bay Masterplan by Australian Museum Business Services for the OCA (Olympic Co-ordination Authority), Prepared by AMBS Consulting, November 1995 for the OCA Sydney. Sydney.

Darcovich, K., and O'Meara, J. (2008). An olympic legacy: Green and Golden Bell Frog conservation at Sydney Olympic Park 1993-2006. *Australian Zoologist* **34** (3), 236–248.

DECC (2008a). Hygiene Protocol for the Control of Disease in Frogs. Threatened Species Management Circular No. 6. Department of Environment and Climate Change, Sydney.

DECC (2008b). Best practice Guidelines. Green and Golden Bell Frog Habitat. Department of Environment and Climate Change, Sydney

Greer, A. E. (1994). Faunal Impact Statement for the Proposed Development Works at the Homebush Bay Brickpit. Prepared for the Property Services Group, Sydney.

Homebush Bay Corporation (1994). 'Homebush Bay Area Masterplan Synopsis August 1994.' (Homebush Bay Co-orporation: Sydney.)

Lips, K. R., Brem, F., Brenes, R., Reeve, J. D., Alford, R. A., *et al*. (2006). Emerging infectious disease and the loss of biodiversity in a Neotropical amphibian community. In 'Proceedings of the National Academy of Sciences of USA 103'. pp. 3165–3170.

McCallum, M. L. (2007). Amphibian Decline or Extinction? Current Declines Dwarf Background Extinction Rate. *Journal of Herpetology* **41** (3), 483–491.

Muir, G. W. (2008). Design of a Movement corridor for the Green and Golden Bell Frog Litoria aurea at Sydney Olympic Park. *Australian Zoologist* **34**, 297–302.

O'Meara, J., and Darcovich, K. (2008). Gambusia control through the manipulation of water levels in Narawang Wetland, Sydney Olympic Park 2003-2005. *Australian Zoologist* 34, 285–290.

Penman, T. D. (1998). Natural factors affecting the early life stages of the Green and Golden Bell Frog, Litoria aurea: Lesson 1829. BSc Hons Thesis, University of New South Wales.

Pyke, G. H. (1995). Fauna Impact Statement for proposed development works at The Homebush Bay Development Area, excluding the Brickpit. Prepared for the Olympic Co- ordination Authority, Sydney.

Pyke, G. H., and White, A. W. (1996). Habitat requirements for the Green and Golden Bell Frog *Litoria aurea* (Anura: Hylidae). *Australian Zoologis*t **30**, 224–232.

Pyke, G .H., and White, A. W. (1999). Dynamics of co-occuring frog species in three ponds utilised by the endangered Green and Golden Bell Frog Litoria aurea. *Australian Zoologis*t **31** (1), 230–239.

Pyke, G .H., and White, A. W. (2000). Factors influencing predation on eggs and tadpoles of the endangered Green and Golden Bell Frog (*Litoria aurea*) by the introduced Plague Minnow (*Gambusia holbrooki*). *Australian Zoologist* **31**, 496–505.

Pyke, G .H., and White, A. W. (2001). A Review of the Biology of the Green and Golden Bell Frog (*Litoria aurea*). *Australian Zoologist* **31**, 563–598.

Pyke, G. H., White, A. W., Bishop, P., and Waldman, B. (2002). Habitat-use by the Green and Golden Bell Frog (*Litoria aurea*) in Australia and New Zealand. *Australian Zoologist* **32**, 12–31.

Smith, K. G., Lips, K. R., and Chase, J. M. (2009). Selecting for extinction: non-random disease-associated extinction homogenizes amphibian biotas. *Ecology Letters* **12**, 1069–1078.

Stuart, Simon N., Chanson, Janice S., Cox, Neil A., Young, Bruce E., Rodrigues, Ana S. L., *et al*. (2004). Status and Trends of Amphibian Declines and Extinctions Worldwide. *Science* **306** (5702), 1783–1786.

Tyler, M. J. (1989). 'Australian Frogs.' (Viking ONeill: Sydney.)

Wassens, S., Arnaiz, O., Healy, S., Watts, R., and Maguire, J. (2008). Hydrological and habitat requirements to maintain viable Southern Bell Frog (*Litoria raniformis*) populations on the Lowbidgee floodplain- Phase 1. Final Report DECC. Queanbeyan.

White, A. W. (2001). Strategic Plan for the Development of Habitat for Green and Golden Bell Frogs. Woonona Brickpit Site. Prepared for MBA Lands Pty Ltd.

White, A. W. (1995). The Green and Golden Bell Frog. *FrogFacts* **5**, 1–4.

White, A. W., and Pyke. G. H. (1996). Distribution and conservation status of the Green and Golden Bell Frog *Litoria aurea*. *Australian Zoologist* **30**, 177–189.

White, A. W., and Pyke, G. H. (2002). Captive frog egg numbers - a misleading indicator of breeding potential. *Herpetofauna* **32** (2), 102–109.